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Longitudinal Analysis of Flexibility and Reorganization in Early Adolescence: A Dynamic Systems Study of Family Interactions

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A dynamic systems (DS) approach was used to study changes in the structure of family interactions during the early adolescent transition period. Longitudinal observational data were collected in 5 waves prior to, during, and after the transition. Boys ($n = 149$ families) were videotaped problem solving with their parents at 9–10 years old and every 2 years thereafter until they were 18 years old. State space grids (a new DS method) were constructed for all families across all waves. Two variables indexing the variability of the family interactions were derived from the grids. As hypothesized, the DS variables revealed a significant quadratic effect related to a peak in variability at 13–14 years of age.

> At this stage in her life Briony inhabited an ill-defined transitional space between the nursery and adult worlds which she crossed and recrossed unpredictably. . . .
>
> —Ian McEwan, *Atonement*

Early adolescence is hypothesized to be a time of dramatic developmental transition, second only to infancy in the magnitude and breadth of concomitant changes (e.g., Lerner & Foch, 1987; Lerner & Villarruel, 1994; Petersen, 1988). Critical transformations occur across several domains and are intricately interrelated. In addition to and perhaps as a result of the changes that the adolescent is undergoing personally, family interactions also shift in character and quality (e.g., Collins, 1990, 1995; Collins & Laursen, 1992; Hill, 1987; Holmbeck, 1996; Holmbeck, Paikoff, & Brooks-Gunn, 1995; Laursen & Collins, 1994; Laursen, Coy, & Collins, 1998; Paikoff & Brooks-Gunn, 1991; Steinberg, 1990). Although a great deal is known about changes in the content and emotional intensity of family interactions over this developmental period (e.g., Csikszentmihalyi & Larson, 1984; Laursen et al., 1998; Montemayor, 1982, 1983; Smetana, 1988; Steinberg, 1990; Youniss & Smollar, 1985), much less is understood about change in the structure of these interactions. By *structure* we mean the relative stability and variability of parent–child interactions, irrespective of their content. Following other developmental theorists (e.g., Ford & Lerner, 1992; Lewis, Lamey, & Douglas, 1999; Thelen & Ulrich, 1991), we suggest that developmental transitions in general and the transition to adolescence in particular are marked by a substantial increase in variability. This peak in variability may be evident in family interactions as well as in individual behavior. In the present study, dynamic systems (DS) principles and a new empirical method derived from these principles are applied to examine systematic changes in the structure of family interactions across the adolescent transitional period.

For boys, a good deal of evidence points to 13 to 14 years as the average age of this transitional period, a time during which most of the dramatic changes occur (Feldman & Elliot, 1990). First, the onset of puberty falls around this age range for boys (approximately 2 years later than for girls; Paikoff & Brooks-Gunn, 1991) and is associated with enormous biological developments, including hormonal and physical changes (e.g., Paikoff & Brooks-Gunn, 1991). As many have pointed out, adolescents essentially grow an entirely different body during this period. Second, early adolescence marks a major cognitive–developmental milestone: the emergence of formal operational thinking (Inhelder & Piaget, 1958; for reviews, see Graber & Petersen, 1991; Keating, 1990). These cognitive changes have been suggested to occur later for boys than girls, around the age of pubertal onset (Graber & Petersen, 1991). Third, new neuroscientific evidence suggests that the brain undergoes massive restructuring during adolescence, particularly in the prefrontal cortex and limbic regions (for a review, see Spear, 2000). It has been speculated that this restructuring is intimately linked to pubertal onset (Graber & Petersen, 1991; Spear, 2000). Fourth, in the sociocultural domain, most North American adolescents experience a dramatic shift when they leave junior or middle school and enter high school, again around

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the age of 13 to 14 years (e.g., Eccles et al., 1993). There is still much debate as to the timing of and connections between biological and cognitive changes, and individual differences are profound in both, but these findings suggest that 13 to 14 years of age constitutes a period of massive reorganization in multiple domains for boys.

Along with the biological and sociocultural shifts, dramatic transformations in the parent–child relationship may be linked to this developmental period (Granic, Dishion, & Hollenstein, in press; Paikoff & Brooks-Gunn, 1991). A number of scholars have suggested that family relationships during early adolescence go through a period of reorganization during which roles and responsibilities are renegotiated and relationships become realigned to represent a more equal balance of power (Collins, 1992; Hartup, 1989; Steinberg, 1990; Youniss & Smollar, 1985). Several comprehensive reviews on the nature of these changes are available (Collins, 1990, 1995; Collins & Laursen, 1992; Hill, 1987; Hill & Holmbeck, 1986; Holmbeck, 1996; Holmbeck et al., 1995; Laursen & Collins, 1994; Laursen et al., 1998; Paikoff & Brooks-Gunn, 1991; Silverberg, Tennenbaum, & Jacob, 1992; Steinberg, 1990).

The majority of these studies have focused on the content of parent–child interactions and how that content changes as the adolescent develops. Generally, conversations and conflicts between parents and young adolescents tend to shift toward issues of personal dress, dating practices, grades, and so on (Montemayor, 1983). Until recently, the frequency and content of disagreements and conflict between parents and adolescents was the main focus of research (Holmbeck, 1996; Smetana, 1996). A meta-analysis of this large body of work revealed that family conflicts increase markedly in early adolescence, gradually abating in the years to follow (Laursen et al., 1998; also see Montemayor, 1983).

The positive aspects of parent–adolescent interactions have also been studied. This research has shown that despite the seemingly ubiquitous increase in negativity during early adolescence, most youth maintain a close, affectionate bond with their parents (e.g., Baumrind, 1991; Collins & Laursen, 1992; Grotevant & Cooper, 1986; Hill, 1987; Hill & Holmbeck, 1986; Larson, Richards, Moneta, Holmbeck, & Duckett, 1996; Smetana, 1988, 1996). In sum, over the past 2 decades, the majority of empirical work has focused on understanding changes in what early adolescents and parents are talking about and how frequently they are doing so. However, we know very little about changes in the structure of family interactions during this transitional phase.

Beginning with the psychoanalysts, theorists have often characterized family transformations in early adolescence as discontinuous and abrupt (e.g., Blos, 1962, 1979; A. Freud, 1937, 1958). More recently, stage theories (e.g., Case, 1985; Fischer, 1980) and sociobiological (Steinberg, 1989, 1990) and cognitive–developmental models (Selman, 1981; Smetana, 1988; Youniss, 1980) have conceptualized this period as one of massive structural reorganization in multiple domains (but see Laursen & Collins, 1994, for an alternative perspective). These approaches view development as a profile or trajectory with periods of relative stability interspersed by periods of variability or fluctuation. However, few empirical studies actually examine this hypothesized developmental profile, particularly as it manifests in parent–child interactions.

Part of the reason for this gap is that our current methods and models are not particularly well suited for studying the structure of interactions and changes in that structure across time (Granic & Hollenstein, in press; Lewis et al., 1999). In addition, few studies that are focused on family interactions during the early adolescent transition follow families longitudinally from late childhood through to the end of adolescence. As a result, most of what psychologists know about changes in adolescence comes from comparisons between younger and older adolescents (Paikoff & Brooks-Gunn, 1991). Also, most studies, even if they are longitudinal, rely on questionnaire and interview data; we are aware of no research in which observational measures of parent–adolescent interactions were collected before, during, and after the hypothesized transitional period.

DS Principles

The current study was designed to address these limitations through a DS analysis of observed family interactions from childhood to late adolescence. Our aim was to extend past research on the content of family interactions during this transitional phase by studying changes in the structure of these interactions.

Developmentalists may be familiar with some of the concepts in the DS framework because of their long-standing familiarity with systems concepts in general. Systems theories that overlap, incorporate, or are related to DS concepts include general systems theory (Sameroff, 1983, 1995; von Bertalanffy, 1968), developmental systems theory (Ford & Lerner, 1992), the ecological framework (Bronfenbrenner, 1979), contextualism (Dixon & Lerner, 1988), the organizational approach (Cicchetti & Schneider-Rosen, 1986), the holistic–interactionistic view (Bergman & Magnusson, 1997), and the epigenetic view (Gottlieb, 1991). In their review of the history and development of this class of models, Ford and Lerner (1992) highlighted the principles shared by systems views. Specifically, these approaches focus on process-level accounts of human behavior and on the context dependence and heterogeneity of developmental phenomena. They are concerned with the equi- and multifinality of development and the hierarchically embedded nature of intrapersonal (e.g., neurochemical activity, cognitive and emotional biases), interpersonal (e.g., parent–child relationships, peer networks), and higher order social systems (e.g., communities, cultures). They are also fundamentally concerned with the mechanisms that underlie change and novelty (as well as stability) in nonlinear developmental trajectories.

For the sake of clarity, we go on to delineate DS principles from other systems approaches in developmental psychology. Formally, a *dynamical system* is a set of equations that specify how a system changes over time. The principles that describe this set of equations make up a technical language originally developed in the fields of mathematics and physics. In concrete terms, dynamic systems are “systems of elements that change over time” (Thelen & Smith, 1998, p. 563). In fields as diverse as physics (e.g., Haken, 1977), chemistry (e.g., Prigogine & Stengers, 1984), biology (e.g., Kauffman, 1993; Kelso, 1995), and neuroscience (Freeman, 1995), DS principles have proven essential for providing process-level accounts of the structure and organization of behavior. Many developmentalists are also drawn to this framework because of the analytic strategies it suggests (e.g., Fogel, 1993; Lewis et al., 1999;

Thelen & Smith, 1994, 1998; van der Maas & Molenaar, 1992; van Geert, 1991, 1994).

Over the past 15 years, a group of developmental psychologists have used the DS framework for the explicit purpose of studying the structural profile of developmental transitions (e.g., Lewis, 2000; Lewis et al., 1999; Thelen & Ulrich, 1991; van Geert, 1991, 1994). Transitions in motor, cognitive, and linguistic development have been modeled by the application of DS concepts that are particularly concerned with the structural profile of change (Case et al., 1996; van der Maas & Molenaar, 1992; van Geert, 1991, 1994).

Specifically, there are three principles that are central to the DS framework with which we are particularly concerned because they are useful for thinking about change and how to measure it (Granic & Hollenstein, in press). First, the discontinuous nature of change in developmental systems is the hallmark principle in DS approaches and has given rise to a set of methodologies grouped under catastrophe theory (e.g., van der Maas & Molenaar, 1992), developmental growth curve modeling (van Geert, 1991, 1994), and the study of phase transitions (e.g., Thelen & Smith, 1994; Thelen & Ulrich, 1991). Second, variability represents critical data in DS research: Increases in variability index a less stable or multistable system, a system at a transition point in development (i.e., a system poised to change). Thus, measures of variability are often considered "the signal, not the noise" (e.g., Ford & Lerner, 1992; Thelen & Ulrich, 1991). Finally, DS theorists are fundamentally concerned with the interrelations between time scales of development and put a great deal of emphasis on understanding the changing patterns of real-time behavior as they relate to changes in developmental patterns (Thelen & Smith, 1998). In the current study, we are most concerned with these last two DS principles of change: variability as an index of a transitional period in development and the link between real- and developmental-time scales with respect to transitional processes.

Phase Transitions in Real and Developmental Time

The analysis of transitions or change as a phase transition makes use of all three principles described above. Thelen and Smith (1994, 1998) have discussed in detail the properties of a phase transition. *Phase transitions* are global reorganizations in the pattern of interacting system elements. DS theorists portray this period as a discontinuous increase in the behavioral variability of a system that then settles down as the system restabilizes. Phase transitions are characterized by interrelated changes in real and developmental time. In developmental time, periods of stability and relative predictability are followed by the destabilization of established patterns. After this period of flux, developmental systems restabilize and settle into new habits or styles of interactions. Corresponding to this developmental profile, behavior in real time is more variable and flexible: From moment to moment, behavior changes from one state to another frequently and is less likely to settle in any one state for very long. However, before and after the phase transition, real-time behavior is far less variable; only a small number of behavioral states are available to the system, and once the system settles into one of these stable patterns, it tends to remain there for an extended period of time. Thus, a discontinuous shift in development corresponds to increased variability observable at two interacting time scales.

In the present study, we examined the hypothesis that boys go through a phase transition in the developmental path of parent–adolescent relationships at 13 to 14 years of age. According to our DS-inspired model (Granic, 2000; Granic et al., in press), the parent and child develop characteristic ways of interacting with each other over the course of childhood. The result is a highly predictable parent–child system that has been configured from many repeated family interactions. For some families, these stable patterns may be characterized generally as supportive and warm. For other families, coercive patterns may have stabilized over time (Patterson, 1982), and for still others, withdrawn and sad dyadic interaction styles may have emerged. Regardless of their content, however, at the onset of the hypothesized phase transition, the family behavioral system may undergo a period of reorganization. This period should correspond with the previously reviewed biological, cognitive, and social changes that characterize early adolescence.

In terms of parent–child interactions, the hypothesized phase transition should be characterized by an increase in the variability of dyadic patterns: New behavioral possibilities should emerge, and the system should change frequently from one behavioral state to another (e.g., from playful to hostile interactions, from teasing to withdrawn behaviors). After the phase transition, the parent–adolescent system should return to a more stable, less flexible behavioral landscape. This conceptualization resonates well with Ford and Lerner's (1992) idea of "disorganization flexibility," which they describe as "one characteristic of the transitional period between disorganization and reorganization . . . [during which] greater diversity in functional patterns is more likely to occur than when life is flowing smoothly in habitual steady states" (p. 199). To further clarify the conceptual model that is the basis of the current study and to demonstrate how it may be tested, we need to introduce an additional DS concept.

State Space Grids

DS theorists often use the concept of a state space to represent the range of behavioral possibilities for a given system. A *state space* is a hypothetical landscape of behavioral habits that have stabilized over development. On the basis of this DS abstraction, Lewis et al. (1999) recently developed a graphical approach that uses observational data and quantifies these data according to two ordinal variables that define the state space for the system. We adapted this technique to study dyadic behavior, specifically parent–adolescent problem-solving interactions (Granic & Lamey, 2002). With this state space grid method, the dyad's behavioral trajectory (i.e., the sequence of behavioral states) is plotted as it proceeds in real time on a grid representing all possible behavioral combinations. The parent's coded behavior is represented on the *x*-axis and the child's behavior is represented on the *y*-axis. Each point on the grid represents a two-event sequence (i.e., a dyadic state). Horizontal lines represent the parent's movement from one behavioral state to another (a conversational turn), and vertical lines represent the child's change from one state to another. For example, a hypothetical trajectory representing seven conversational turns is presented in Figure 1. Seven successive events are plotted: child neutral, parent neutral, child hostile, parent neutral, child hostile, parent hostile, and child hostile.

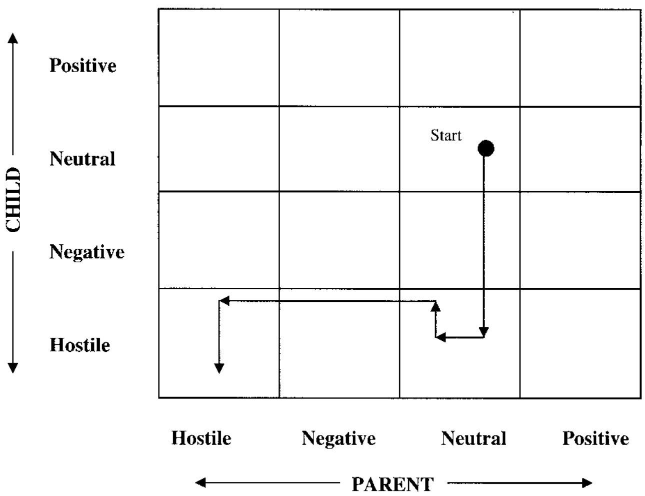

Figure 1. Example of a state space grid with a hypothetical trajectory representing the following seven events: child neutral, parent neutral, child hostile, parent neutral, child hostile, parent hostile, child hostile.

With this temporally sensitive technique, we were able to examine whether behavior clusters in very few or many regions (i.e., cells) of the state space. We could also track how long the trajectory remained in each cell and how quickly it moved between cells. If a dyadic trajectory remains in a small number of cells and makes very few transitions between cells, this dyadic system may be thought of as stable or inflexible. In contrast, a trajectory that moves around to many cells in the state space grid and makes frequent changes between these cells may indicate a highly flexible or variable system. This method was particularly useful for our purposes because unlike many conventional approaches (e.g., sequential analyses, growth curve modeling), information can be represented and analyzed at the dyadic, systemic level. Another advantage of this technique over traditional statistical methods is that it is designed to measure changes in the qualitative patterns of dyadic interactions.

In the current study, we applied the state space grid method to study changes in the structure of parent–son problem-solving interactions before, during, and after the ages of 13 to 14 years (the hypothesized phase transition). We expected that interactions during preadolescence (ages 9 to 12 years) would be stable and confined to a small number of regions on the state space. At the phase transition (ages 13 to 14 years), we hypothesized that grid patterns would become less organized and more variable. Finally, after the transition (ages 15 to 18 years), we expected patterns to restabilize. Figure 2 summarizes our model and demonstrates a generic example of the sequence of state space grids we expected to find if indeed the developmental profile of the parent–child system exhibited properties of a phase transition. It is important to note that we were not interested in examining the content of these family interactions. Our aim was to identify previously undetected changes in the structure (i.e., the flexibility/variability) of these interactions.

To test the hypothesis, we examined a longitudinal dataset with observational data collected in five waves prior to, during, and after the hypothesized phase transition. Parents and children were observed in problem-solving interactions when children were 9 to 10 years old and every 2 years thereafter until they were 17 to 18 years old. Thus, two waves of data were collected before the hypothesized phase transition, one wave during the transition, and two more waves after this period. On the basis of these observational data, state space grids were constructed for all families across all waves. Two variables indexing the relative variability versus stability of the interactions were derived from these grids. Statistical analysis of these variables was expected to reveal a quadratic pattern: Flexibility values were expected to be low in the first two waves, highest in this third wave, and then low in the last two waves again.

Method

Participants

Participants in the study were a subsample of the boys involved in the Oregon Youth Study (OYS). The original sample comprised 4th-grade boys recruited from schools in higher crime areas in a medium-sized metropolitan region of the Pacific Northwest. Of the 277 eligible participants, 206 elected to participate in the OYS. Recruitment details, demographic information, and more information on the comprehensive assessment battery for the full sample are summarized by Capaldi and Patterson (1987). The data reported here were based on the 149 families who participated in all five waves of observational data collection. At the first wave, the boys were in 4th grade (9 to 10 years old), and observational data were collected every 2 years thereafter when they were 11 to 12, 13 to 14, 15 to 16, and 17 to 18 years old.

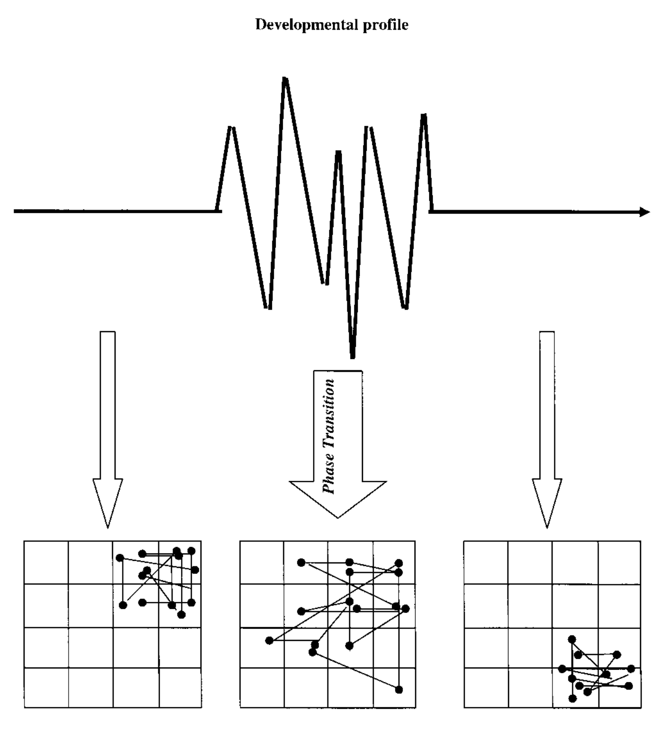

Figure 2. Model of a developmental phase transition in early adolescence. Developmental phase transitions are periods of fluctuation in developmental time and increased variability in real time.

In terms of demographic information, the sample was primarily Caucasian; 130 boys (87.2%) were Caucasian, 3 (2.0%) were African American, 3 (2.0%) were Native American, 3 (2.0%) were Mexican American, and 10 (6.7%) did not identify themselves as part of any of these ethnic groups. At the time of the first observation, mothers' median age was 33.4 years old. Ninety boys (60%) came from two-parent families; the rest were from single-mother homes. Finally, socioeconomic status was estimated by the highest level of education attained by the mother. Twenty-seven (18.1%) mothers did not complete high school, 57 (38.3%) graduated from high school, 47 (31.5%) had completed some college or vocational training, 10 (6.7%) completed college, and 3 (2.0%) completed graduate or professional school. Data on educational status were unavailable for 5 mothers.

The 149 participants that represented our subsample of boys from the OYS were compared with the 57 boys who were eliminated from this study because they did not complete all five waves of observational data collection. In terms of ethnic differences, all but 1 of the 57 boys that were eliminated were Caucasian. Mothers' highest level of education was also compared between the two groups. The mothers of the 57 excluded boys had completed significantly less schooling than the mothers included in the current sample, $t(193) = 2.18$, $p = .03$ (data were unavailable for 6 excluded and 5 included families).

Because the OYS sample was originally recruited to study the development of antisocial behavior, the two groups were also compared on the severity of antisocial behavior at each wave of data collection. A construct was created (for studies previously conducted on this sample) that combined standardized teacher (e.g., Teacher version of the Child Behavior Checklist, CBCL; Achenbach, 1991b), parent (e.g., Parent version of the CBCL; Achenbach, 1991a; interviews), peer (e.g., peer nominations), and self-report measures of antisocial behavior. The measures that compose the construct, the number of items on each measure, sample items, and corresponding Cronbach's standardized alphas and Pearson correlations are reported in detail elsewhere (Capaldi, Dishion, Stoolmiller, & Yoerger, 2001; Capaldi & Patterson, 1987). Finally, *t*-test comparisons at each of the five waves revealed that the excluded group was significantly more antisocial at every wave than the current subsample of 149 boys: Wave 1, $t(204) = 2.75$, $p < .01$; Wave 2, $t(199) = 3.04$, $p < .01$; Wave 3, $t(199) = 2.51$, $p < .05$; Wave 4, $t(196) = 2.18$, $p < .05$; Wave 5, $t(202) = 2.39$, $p < .05$. Thus, the subsample used in the current study seems to represent a less at-risk or more normative group than those families who were excluded for having failed to complete at least one observational assessment session.

Procedure

Each wave of data collection consisted of videotaped problem-solving discussions between the boy and 1or 2 parents. In the original project from which the current data were derived, problem-solving interactions were chosen as the observational task because there is extensive evidence that suggests that these tasks differentiate clinic-referred from normal children and adolescents and that problem-solving skills are generally important for healthy adolescent development (e.g., Borduin, Henggeler, Hanson, & Pruit, 1985; Dodge, 1985; Kazdin, Esveldt-Dawson, French, & Unis, 1987; Robin, 1981). Problem-solving interactions with adolescents have also been used to study the frequency and content of conflict in normal adolescents and parents (Laursen & Collins, 1994; Laursen et al., 1998). We were interested in using the same laboratory paradigm to extend the past work on problem-solving content by studying changes in the structure of these types of family interactions.

As a warm-up activity, the parents and adolescents spent 5 min planning a fun activity. Then they spent 20 min attempting to resolve two high-conflict family issues. The topics of the discussions were selected by the parents and adolescents from an adapted version of the Issues Checklist (Prinz, Foster, Kent, & O'Leary, 1979), which lists topics of frequent family conflicts (e.g., chores, school problems, allowances, curfews). Parents and adolescents were each asked to discuss the issue that they had rated as "hottest." Parent- and adolescent-identified issues were counterbalanced for order such that the adolescent problem was discussed first approximately 50% of the time. Results from the two problem-solving sessions were combined in the current data analysis.

Coding and Data Reduction

The videotaped problem-solving sessions were coded using the Family Process Code (FPC; Dishion, Gardner, Patterson, Reid, & Thibodeaux, 1983). The FPC is a real-time coding paradigm that categorizes each unique behavior into 1 of 25 verbal or physical "content" codes and 1 of 6 "valence" codes such that every recorded content behavior is qualified by valence. Each coded behavioral event is recorded in four parts: the initiator of the behavior, the content code, the recipient of the behavior, and the affect the initiator exhibited. Coders were trained extensively over a 3-month period, and reliability was maintained at a minimum of 75% agreement and .65 kappa for all five waves of observational data. Reliability checks were done on a randomly selected 15% of the sessions. Coders were assigned to be either the calibrator or the one being checked for reliability such that each coder had a proportionately equal number of opportunities in either role. Coding disagreements were only used for ongoing training and resolved during that training phase. The calibrator's data were kept for analyses.

For the current study, the raw observational codes were collapsed into four categories: hostile, negative, neutral, and positive (see Appendix for details). The amalgamation strategy was based on Snyder, Edwards, McGraw, Kilgore, and Holton's (1994) dimensional system in which they categorized ratings of parent–child behaviors along a 10-point continuum from 0 (*most positive*) to 9 (*most aversive*). Informed by the Snyder et al. system, we separated negative codes into two categories: negative and hostile. This was done to distinguish behaviors that might be considered negative but not hostile or contemptuous (i.e., disagree, deny) from those behaviors that were intended to attack, diminish, or degrade the other (i.e., criticize, threaten). Primarily, the difference between these two categories was the affect with which behaviors were expressed: Negative behaviors were accompanied with either neutral or mildly negative affect whereas hostile behaviors were expressed with strong negative affect or hostility.

If both mother and father participated in the problem-solving discussion, their codes were combined into one parent code. Thus, the coding system was consistently dyadic: Parental behavior was rated on one scale and the boy's behavior on another.[1] The data were further collapsed into a dyadic turn-taking format such that when two or more codes from the same dyad member (parent or boy) immediately followed each other, the category of the highest priority was retained (this happened less than 5% of the time across all dyads). The prioritization of categories was determined by the following hierarchy: hostile, negative, positive, neutral. For example, if the mother was coded as neutral followed by the father coded as negative followed by the boy coded as positive, that sequence was recorded as "parent negative—boy positive." This prioritization was based on a conceptual assumption that the more affectively strong utterances were the most salient to each dyad member. Thus, a neutral statement would not have as much impact on the other person as a positive or negative one, and hostile statements were paid attention to more than negative statements. It was very rare that a positive and negative statement would occur in the same conversational turn, but again, the same logic was followed that a supportive or encouraging statement would probably be obscured by a hostile or negative one.

[1] Separate analyses were run on only the single-parent ($n = 61$) dyads who had the mother consistently participating across all five waves. The results were virtually identical to those reported here for the full sample.

State Space Grid Analysis

The turn-taking data stream was plotted on state space grids. As described earlier, grids were created so that each point represented a dyadic turn. When the dyad's behavior changed, a new point was plotted and a line was drawn to connect them. Thus, a trajectory of real-time dyadic behavior was traced. State space grids for each family at each wave were created by plotting the boy's behavior on the *x*-axis and the parent's behavior on the *y*-axis. Splus 2000 was used to create the grids.

Next, two variables designed to measure the flexibility of interaction patterns were derived from the state space grids. The first variable was a count of the total number of unique cells (TUC) that the dyad occupied on the state space grid. A high TUC value indicated a more flexible behavioral pattern (i.e., the dyad was observed in many different behavioral states); a low TUC value corresponded to a more stable, less flexible grid pattern. The second variable created was the total number of cell transitions (TCT) between the cells on the state space grid. This was a measure of how often behavior changed during the session and was calculated by counting the number of different lines plotted on the state space grid. A high TCT value indicated a more flexible behavioral pattern (i.e., dyads often changed from one state to another); a low TCT value indicated a more stable pattern (i.e., dyads remained unchanged in the same behavioral state for long periods of time). These measures were designed to capture two different aspects of flexibility. Thus, it was possible for one grid to have a low TUC value with high TCT values (i.e., a small number of occupied cells with a high number of transitions) and vice versa (see Figure 3).

To assess the reliability of the two variability measures, we ran a variant of test–retest reliability. At each wave, the correlations between the first and second problem-solving sessions on TUC and TCT values were examined. For TUC, correlations between the two interaction sessions ranged from $r = .53$ to $r = .61$ ($p < .01$), and for TCT, correlations ranged from $r = .58$ to $r = .67$ ($p < .01$). We were encouraged by the moderate to high correlations indicating that the structural measures showed stability across sessions.

Results

Preliminary Analyses

To ensure that our two measures, TUC and TCT, were accounting for unique aspects of the structure of the state space grids, we first ran bivariate correlations at each of the five time points. The correlations between TUC and TCT measures ranged from .33 to .57 ($p < .01$) for all five waves. Thus, there was statistical overlap between these two measures, but the moderate magnitude of the correlations indicated that the measures also captured unique aspects of flexibility.

Given the moderate correlations between the two variables, a number of possible state space patterns were possible because of different combinations of the TUC and TCT variables. Figure 3 illustrates the potential range of state space grid patterns displayed. We chose the grids for Figure 3 from separate families to illustrate how the combination of high and low TUC and TCT values can be represented on a grid. A flexible dyad may exhibit the grid pattern shown in the top right panel in Figure 3 (high values on both variables) in which the dyadic trajectory seems almost random with frequent changes among almost all possible states. Alternatively, a dyad with low scores on both variables clearly exhibits a less variable, more stable behavioral pattern with very few cells occupied and few transitions among the cells (bottom left panel). If one variable or another is high and the other is low, the grid

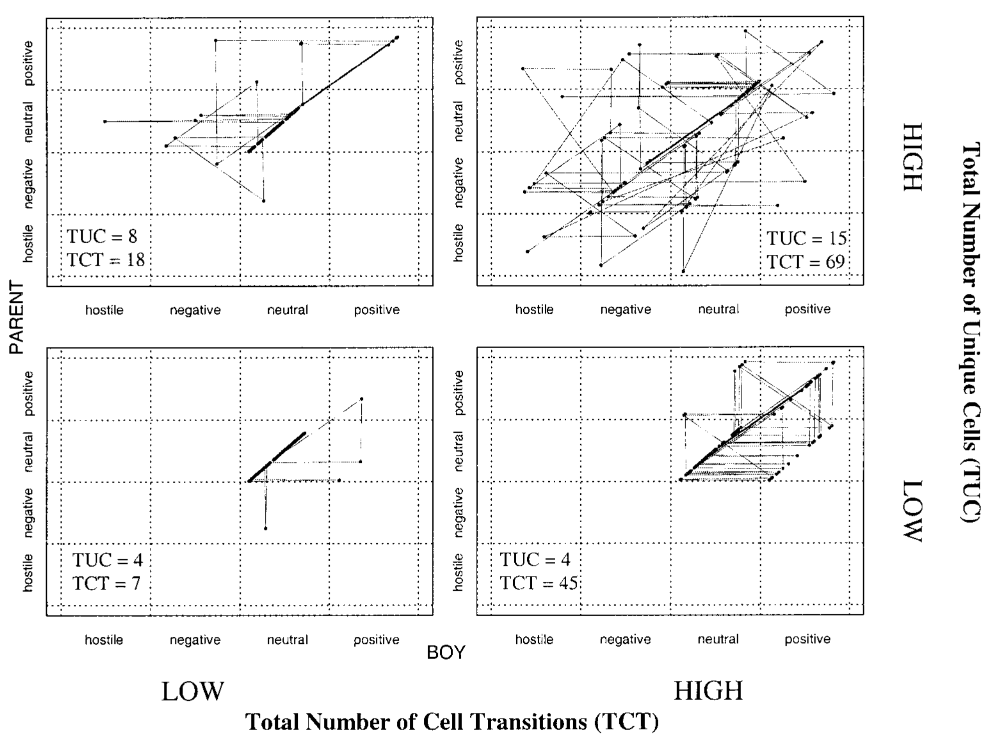

Figure 3. An example of the range of state space grid patterns showing combinations of high and low TUC and TCT values.

patterns may look similar to the bottom right and top left panels. For example, a dyad may be regarded as flexible in some respects (on the basis of the TCT measure) but not others if they show the grid pattern exemplified in the bottom right panel; this dyad visited very few cells on the grid, but moved a great deal among those cells (hence the high TCT value).

Developmental Analyses

As a first step toward examining whether variability in family interactions peaked during the hypothesized phase transition (ages 13 to 14 years old), we visually examined the longitudinal sequence of state space grids for each family. Figure 4 shows one family's state space grids across the five waves. Consistent with our hypothesis, this was a characteristic pattern for the sample: The sequence of state space grids showed that behavior became more variable (i.e., occupied more cells and moved around the grid more frequently) at the third wave. Before and after this period, dyadic behavior looked more stable and less flexible; fewer cells were occupied, and there were fewer changes between cells.

To quantify these impressions, we calculated the two flexibility measures, TUC and TCT, for each dyad at each wave. As shown in Figures 5 and 6, the developmental pattern for both measures of flexibility supported our hypothesis that the age of 13 to 14 years for boys was marked by a rise in the variability of family interactions and was followed by a drop in these values after the transition period. We ran a series of repeated-measures ANOVAs to establish the statistical significance of this developmental pattern. As expected, for TUC, a significant quadratic effect was found, $F(1, 148) = 35.49$, $p < .001$. Likewise, the TCT variable showed a significant quadratic effect, $F(1, 148) = 8.36$, $p < .01$.

It was possible that our results were a function of the length of the interaction sessions; instead of representing more variability in the middle wave, the higher TUC and TCT values could have been due to dyads engaging in more conversational turns during that wave. To guard against this conflation, we divided TUC and TCT values by the number of conversational turns and reran the ANOVAs with these modified dependent variables. Controlling for the number of turns in this way strengthened the effects; a significant quadratic peak at the middle wave was revealed for both TUC, $F(1, 148) = 52.18$, $p < .001$; and TCT, $F(1, 147) = 23.5$, $p < .001$.

These results were indeed encouraging, but we conducted an additional set of analyses that was intended to maintain the integrity of individual family interactions and thus to be a more faithful translation of systems approaches to data analysis (Granic & Hollenstein, in press; Richters, 1997). We applied a case-based approach to examine whether the peak in variability at 13 to 14 years old was not only a central tendency for the sample as a whole, but whether it also represented a characteristic developmental profile for most individual families in the sample. For each family, we recorded the longitudinal wave at which the greatest number of cells were occupied and the greatest number of transitions were made (i.e., the wave at which TUC and TCT values peaked for each family). As shown in Figure 7, the highest percentage of families showed a peak in TUC and TCT values at the hypothesized phase transition age. Not surprisingly, individual differences were also observed. But it is particularly interesting to note the relatively normal distribution of these results, suggesting

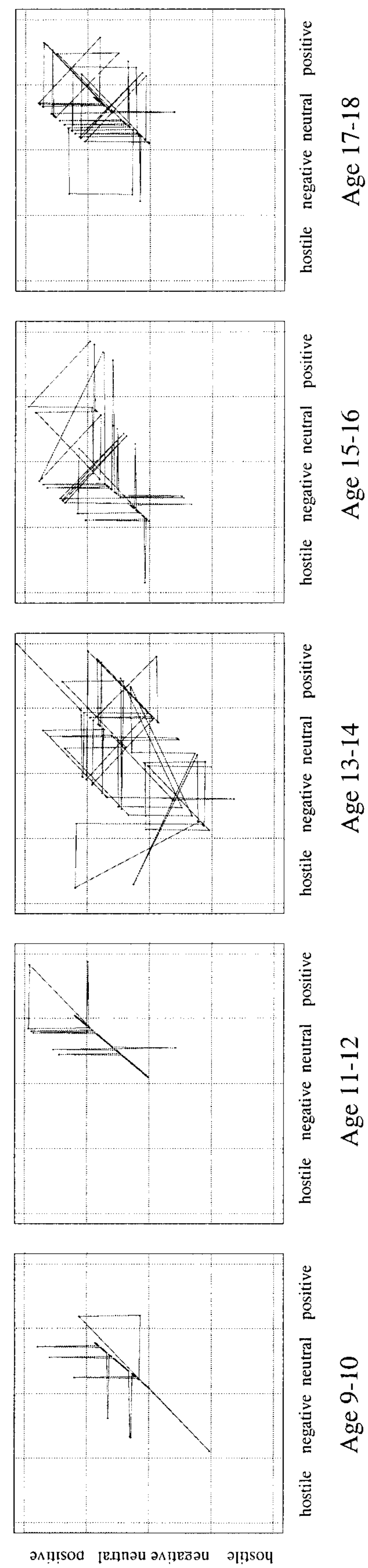

Figure 4. Sample state space grids for one family across five longitudinal waves.

Figure 5. Mean number of unique cells occupied at each wave.

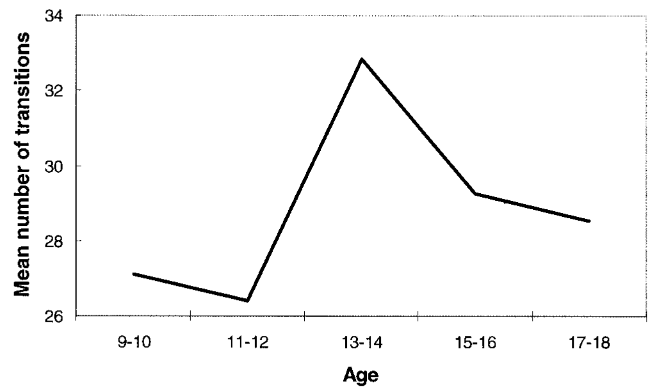

Figure 6. Mean number of transitions at each wave.

that although some families did peak in flexibility in the years just before and after the hypothesized phase transition, hardly any dyads peaked in the first and last wave (with the exception of TCT values in the first wave).

Finally, we wanted to examine whether our findings were merely replicating previous research that has found conflict and negativity to increase during early adolescence. Although this would not be an adequate explanation for the peak in number of transitions, the increase in number of unique cells occupied could be a result of dyads beginning to engage in more conflictual (hostile or negative) interactions at the middle wave. We ran repeated-measures ANOVAs on the combined frequencies of the four kinds of conflict possible within our categorization system: all dyadic combinations that included hostility and negativity (the bottom left quadrant of the state space grid). Figure 8 shows the significant quadratic effect for the frequency of dyadic events in the conflict quadrant across the five waves, $F(1, 148) = 47.66, p < .001$. Unlike our flexibility measures, the measures for conflict peaked at the fourth time point, when the boys were 15 to 16 years old, not the third. Thus, our results from the flexibility analyses could not be explained simply by a rise in conflict.

Discussion

The present study was designed to examine longitudinally the reorganization of parent–child interaction patterns across a period associated with multiple developmental changes for boys. With the application of DS principles and a new methodological strategy, we tested the hypothesis that, for boys, the ages of 13 to 14 years constitute a phase transition for the parent–adolescent system. According to this hypothesis, we expected that regardless of the content, the structure of family interactions would show a characteristic developmental profile marked by a peak in the variability of behavioral patterns during this period.

To test our hypothesis, we constructed dyadic state space grids that represented five separate waves of parent–child interactions from childhood to late adolescence. Variables that captured different aspects of flexibility in dyadic interactions were subsequently derived from the grids. Results strongly supported our hypothesis that early adolescence is a period of increased flexibility in the parent–child behavioral repertoire. Both the number of different dyadic states and the number of transitions between these states peaked when boys were 13 to 14 years old.

These findings extend previous research on the transitional nature of family relationships during early adolescence by suggesting that the structure of parent–adolescent interactions may be as important as the content and frequency. Our results do not contradict the seemingly ubiquitous finding that conflict and negativity increase during this period. However, the data do point to a more complex, multifaceted picture of the changes that occur during this time. The peak in the number of unique cells visited

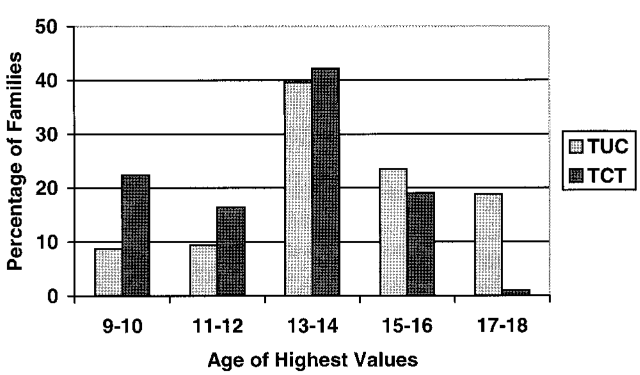

Figure 7. Percentage of families that showed a peak in values for total number of unique cells (TUC) and total number of cell transitions (TCT) at each longitudinal wave.

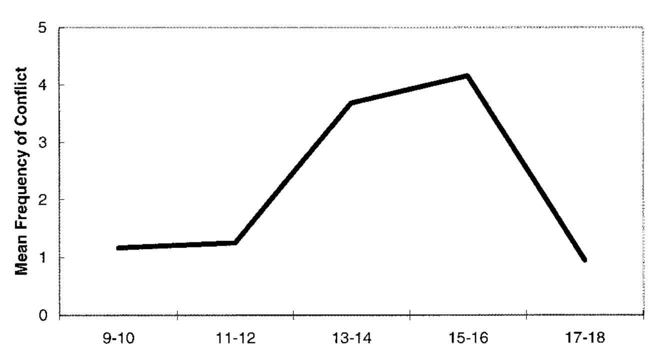

Figure 8. Mean frequency of dyadic events in the quadrant representing conflict across the five waves.

at 13 to 14 years old could have been due to the increase in the frequency of visits to the quadrant of the state space that represented conflict. Although results indicated that the conflict quadrant did increase in frequency at the third wave, it peaked in the fourth wave when overall flexibility had decreased. Thus, the rise in conflict could not alone have accounted for the developmental profile of flexibility.

More importantly, our main findings showed that the number of unique cells visited overall increased during the middle wave. If interactions merely changed in content from being positive or neutral during childhood to hostile or negative during early adolescence, then the number of unique cells occupied would have remained constant across waves. Instead, the middle wave was characterized by an increase in the number of behavioral states available to the dyad—a rise in variability. Furthermore, we found a peak in the second variability measure, number of transitions. An increase in conflict does not explain this result. In fact, it may be expected that an increase in conflict would correspond to fewer transitions because negativity and conflict are often absorbing states that capture behavior for long periods.

What are some potential psychological mechanisms that may account for the rise in behavioral variability at the onset of adolescence? In previous work (Granic et al., in press), we argued that because of the emergence of new interpersonal goals, adolescents begin to play a much more active role in initiating and controlling family interactions than they did in childhood. Pubertal development (Hill, Hombeck, Marlow, Green, & Lynch, 1985; Steinberg, 1987, 1989) and increased time outside the home with peers (Hill, 1987) may give rise to beliefs and goals that are incompatible with those of parents. An increasing capacity to reason abstractly may also prompt young adolescents to reevaluate the hierarchy of family roles and negotiate more egalitarian relationships (Selman, 1981; Youniss, 1980). But parents may resist relinquishing their position of authority, especially when the youth is just entering adolescence. Accordingly, the studies of Collins (e.g., Collins, 1990, 1992, 1995) and of Collins and Laursen (1992) have shown that discrepancies between parents' and adolescents' expectations are greatest during early adolescence compared with childhood and late adolescence. For all these reasons, the family system seems to undergo a period of flux during early adolescence.

In terms of the increase in flexibility we observed, the concurrent and interrelated changes in biological, cognitive, and social domains may trigger family members to initiate innovations in their established ways of relating to one another. However, these attempts at creating novel interaction patterns do not take hold immediately. Instead, what we may be observing in the pattern of increased flux is a trial and error process of adding new behavioral patterns to the family repertoire while still maintaining some of the old ones and moving frequently from one state to another in an attempt to come to a resolution. As the adolescent passes through this phase transition, a new landscape of relational possibilities may stabilize for the family system as flexibility decreases again.

Collins's (1992) model of adolescent development is particularly resonant with this DS view: He refers to the tail end of this transitional phase as a time for the "re-establishment" of stability. The current study is the first of which we are aware that tests empirically this structural conceptualization. Our results are also consistent with hypotheses about structural change integral to developmental stage theories (e.g., Case, 1985; Fischer, 1980), sociobiological theories (Steinberg, 1989, 1990), and social–cognitive models of development (Selman, 1981; Smetana, 1988; Youniss, 1980) that posit a period of reorganization around early adolescence.

Our case-based analysis further supported our hypothesis, emphasizing that the peak in variability in the middle wave was not just a central tendency for the sample as a whole; it also represented a characteristic developmental profile for the greatest percentage of families. But the results also suggested an important pattern of individual differences. The normal distribution of the TUC variable (and a similar, although not as clean, trend for TCT) showed that almost no families peaked in variability in the first and last waves—pre- and late adolescence. These findings are encouraging in that they suggest that our new DS-based structural measures are corresponding to the timing of the majority of changes that have been examined during this period. It may be that increased variability in parent–child interactions systematically relates to individual differences in the timing and onset of major developmental perturbations, including puberty and transitions to a new school environment.

It is important to note that there are limits to the generalizability of the current study. Our results only speak to the structural changes in parents' interactions with boys. Future researchers should examine whether our findings can be replicated with girls. Because girls begin puberty earlier than boys (around 12 years old), it is possible that their family relations undergo a phase transition earlier. Thus, we suspect that a peak in variability may be evident at around the age of 11 to 12 years for girls and parents.

Another limitation may have been in our conceptualization and measurement of what constitutes a family. Consistent with the family systems perspective (Minuchin, 1974), we treated two-parent families as one dyadic system comprising the parents as one unit and the child as the other. Interestingly, this view was supported empirically in that we found no differences in the results when we analyzed one-parent versus two-parent families. However, it may still be important to develop a method that could capture the real-time trajectory of triadic interactions. Also, given that most family interactions do not occur in isolation, siblings might be important to include in the flexibility analysis. As yet, the state space grid method is not malleable enough to accommodate more than dyadic relations, but we are encouraged by new methodological innovations by other DS researchers (e.g., Guastello, 1995) whose techniques may be adapted to study family interactions with more than two members.

Another potential limitation relates to the state space grid variables themselves. Although our results supported our main hypothesis, the generalizability and reliability of the new DS measures will need to be established more systematically through additional research. Finally, we have made broad theoretical arguments about the increase in families' behavioral flexibility during a phase transition on the basis of one type of interaction task, a problem-solving scenario. It may be that these same longitudinal patterns would not have been evident had we asked families to play a game or perform a clean-up task, for instance. Future researchers who examine the family structural changes associated with adolescent development may need to establish whether the same profile is evident across diverse interaction contexts.

Despite these gaps, the current findings represent the first analysis of changes in the structure of parent–adolescent interactions across a recognized developmental transition period. The longitudinal nature of the present study and the use of observational measures to assess changes in parent–child interactions are also strengths that address critical gaps in past research. Moreover, the study demonstrates the utility of applying new DS methods and models to the study of family interactions over time. Although the development of these new methods is clearly just beginning, we are encouraged by our results, and we continue to explore the potential benefits of combining DS techniques with more established statistical methods.

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Appendix

Family Process Code (FPC) Behavioral Codes by Category

FPC content codes	FPC valence codes
Hostile	
Verbal attack, coerce, ambiguous coerce, refuse, physical aggressive, physical attack	Exuberant, positive, neutral, negative, unrestrained negative, sad
Positive verbal, talk, negative verbal, endearment, tease, request, command, ambiguous request, ambiguous command, agree, vocal, positive nonverbal, neutral nonverbal, negative nonverbal, touch, hold, physical interact, comply, noncomply	Unrestrained negative
Negative	
Negative verbal, negative nonverbal, noncomply	Exuberant, positive, neutral, negative, sad
Command	Exuberant, positive, neutral, negative, sad
Positive verbal, talk, endearment, tease, request, ambiguous request, ambiguous command, agree, vocal, positive nonverbal, neutral nonverbal, touch, hold, physical interact, comply	Negative, sad
Neutral	
Talk, tease, request, ambiguous command, vocal, neutral nonverbal, physical interact	Neutral
Ambiguous request, comply	Neutral
Positive	
Positive verbal, endearment, agree, positive nonverbal, touch, hold	Exuberant, positive, neutral
Talk, tease, request, ambiguous request, ambiguous command, vocal, neutral nonverbal, physical interact, comply	Exuberant, positive

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